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Sustainability by Efficiency: Energy Considerations in IoT Device Development

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ABSTRACT

The widespread use of Internet of Things (IoT) devices has brought about an unparalleled level of connectedness, revolutionizing several sectors and everyday existence. However, there are serious worries over the energy usage and environmental effect of these devices due to their increasing deployment. The urgent problem of improving energy efficiency in Internet of Things devices is explored in this study abstract. Acknowledging the complex issues, we examine the condition of IoT device architecture at the moment, focusing on elements that lead to excessive energy usage. We examine cutting-edge techniques via an extensive examination, such as advanced computing paradigms like edge and fog computing, low-power hardware design, and energy-efficient communication protocols. The study also looks at case studies and tests conducted in the real world, providing concrete proof of the efficacy of various energy-saving strategies. Even with significant progress, issues with security, privacy, and scalability still exist. We address the trade-offs between performance and energy efficiency, highlighting the necessity of standardizing solutions. Promising future prospects are outlined in our article, such as the incorporation of block chain applications, revolutionary developments in battery technology, and renewable energy sources. The purpose of this study abstract is to direct researchers, industry practitioners, and policymakers towards sustainable solutions for reducing the energy footprint of Internet of Things devices by offering a thorough view of the present scenario and forward-looking tactics.

Keywords: Blockchain; Dynamic; Ecosystem; Edge computing; Energy efficiency; LPWAN; Internet of Things (IoT); Device architecture.

1. Introduction

A new age of unparalleled connectedness and technological integration has been ushered in by the Internet of Things (IoT), which has completely changed how gadgets interact, communicate, and gather data. The potential for transformation is enormous, given the billions of IoT devices that are now in use worldwide, which range from industrial sensors to smart household appliances. However, the high energy consumption of these networked devices has emerged as a major concern as a result of their growth.

1.1. Background of the Study

The frictionless transfer of data between devices, which builds an interconnected network capable of offering real-time insights, automation, and improved user experiences, is the cornerstone of the Internet of Things. Concerns about the Internet of Things' influence on the environment and sustainability have grown in importance as the number of connected devices keeps rising. IoT energy needs put a pressure on power supplies and increase carbon footprints; thus, an analysis of energy efficiency in this technology paradigm is necessary.

1.2. Motivation of the Study

The realization of the negative effects that wasteful energy usage in Internet of Things devices has on the environment and the economy is what spurred this research. As more and more companies and societies rely on IoT solutions, solving the energy consumption problem is essential to guaranteeing sustainability over the long run. In order to promote a more responsible and environmentally friendly Internet of Things ecosystem, there is also an incentive to investigate novel strategies that strike a balance between the increasing need for connection and the need to reduce energy footprints.

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1.3. Objectives of the Study

Through an analysis of the architecture and other variables impacting energy consumption, this research aims to thoroughly analyse the present level of energy efficiency in Internet of Things devices. The goal of the study is to present a comprehensive overview of the cutting-edge techniques used to improve energy efficiency, from innovative communication protocols to hardware optimizations. Empirical evidence of the efficacy of different techniques will be presented through an examination of real-world case studies and experiments. In addition, the study envisions sustainable solutions that make use of cutting-edge technology and processes by looking forward and suggesting future approaches. By focusing on these goals, our study helps academia, business, and government make important decisions that will direct the creation of IoT ecosystems that are energy-efficient.

2. Literature Review

The body of research on energy efficiency in Internet of Things (IoT) devices is extensive, with several papers covering different facets of power usage, optimization techniques, and environmentally friendly alternatives. A brief summary of the major conclusions from pertinent research is provided in this section.

2.1. Device Architecture and Energy Consumption

Comprehending the energy consumption patterns of Internet of Things devices requires an understanding of their design. Atzori [1] research highlights the difficulties related to energy efficiency and offers a fundamental viewpoint on the architecture of the Internet of Things. Subsequent research examining certain factors impacting energy use builds on this work. Pathirana [2] in their investigation of energy-efficient IoT sensor nodes, agreed. The architecture of Internet of Things devices has been thoroughly studied by researchers to find trends in energy usage. Research conducted by Perera [3] highlights the significance of comprehending the constituents that lead to energy usage, such as processing units, communication modules, and sensors.

2.2. Energy-Efficient Communication Protocols

Reducing energy usage is largely dependent on having effective communication protocols. While Guo [4] focus on network architecture optimisation to improve energy efficiency, research by Gubbi [5] highlights the significance of choosing energy-efficient communication protocols. When it comes to IoT operation that is energy-efficient, communication protocols are essential. A seminal research in this field is the work of Dunkels [6] on the Contiki operating system and its lightweight communication protocols. In Internet of Things networks, communication protocols have a big influence on energy usage. The creation of energy-efficient communication protocols is explored in the works of Shi [7] and Bormann [8], with an emphasis on reducing data transmission overhead and maximizing network traffic.

2.3. Edge Computing and Fog Computing

Combining edge and fog computing has become a viable approach to improve energy economy. A thorough introduction of fog computing is given by Bonomi [9], who also emphasize how it may be able to minimize the amount of data that is transmitted to centralized clouds. Emerging as promising approaches to improve energy efficiency are edge and fog computing. The advantages of shifting processing responsibilities to edge devices are

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investigated by Zhang [10], which lessens the requirement for substantial data transfer to centralized servers. According to Shi [11], edge computing is a potent paradigm that can lower latency and improve energy efficiency.

2.4. Machine Learning for Energy Prediction and Optimization

The application of machine learning to energy optimizations and prediction is becoming more popular. Intelligent energy management is made possible by research by Kang [12] that investigates the application of machine learning algorithms for forecasting energy usage in Internet of Things devices. Yousefpour [13] found that machine learning algorithms help forecast and optimize energy usage in Internet of Things devices. IoT device energy usage has been predicted and optimized through the use of machine learning techniques. Ma [14] and Li [15] have conducted research that show how machine learning models work well for dynamically modifying device settings to increase energy efficiency.

2.5. Energy Harvesting and Sustainable Approaches

As Huang [16] argue, energy collecting technologies open up the possibility of using sustainable energy sources in Internet of Things devices. Furthermore, the integration of renewable energy sources and long-term energy efficiency is examined in Li [17] work. Utilising ambient energy sources is crucial for IoT operations that are sustainable. Research by Chandrakasan [18] sheds light on technologies for energy harvesting, such as solar and kinetic energy, which are used to power Internet of Things devices. In an effort to give Internet of Things devices sustainable power sources, energy collecting methods including solar and kinetic energy harvesting have been studied. Roy [19] and Sudevalayam [20] have made noteworthy contributions that demonstrate the possibility of utilizing ambient energy to power devices for extended periods of time.

2.6. Low-Power Hardware Design

A key component of reducing the energy footprint of Internet of Things devices is the creation of energy-efficient hardware. A groundbreaking study on WISP, a battery-free platform, demonstrating cutting-edge low-power design concepts, is presented by Ransford [21]. Further research concentrating on hardware-level optimizations is motivated by this work. Optimizing hardware is essential for increasing energy efficiency. Sanjith and Manju Bargavi's [22] seminal study on low-power hardware design approaches highlights the necessity of energy-aware circuits in order to minimize power usage in both active and idle phases.

2.7. Challenges and Future Directions

Yassein [23] examine obstacles to energy efficiency, including trade-offs and security issues. Furthermore, intriguing future avenues are outlined in the work of Li [24], such as the combination of blockchain technology with renewable energy sources. Notwithstanding notable advancements, obstacles including security, uniformity, and expandability continue to exist. Roman [25] and Ray [26] have shed light on these issues, while Liu [27] have suggested that block chain technology and renewable energy sources be integrated to create secure IoT ecosystems.

3. Energy Consumption Challenges in IoT Devices

IoT device energy consumption issues are complex and affect the devices' long-term sustainability, scalability, and broad acceptance. Gaining an understanding of these obstacles is essential to creating tactics that effectively

improve energy efficiency in the quickly growing Internet of Things environment. The following are the main issues with IoT devices' energy consumption:

3.1. Limited Power Resources

Numerous Internet of Things devices rely on battery power, and the restricted capacity of batteries is a notable obstacle. It might not be feasible to regularly replace or recharge IoT devices' batteries since they are frequently placed in isolated or difficult-to-reach places. To extend the device's lifespan, effective energy management is required in light of this constraint.

3.2. Heterogeneity of Devices

The Internet of Things (IoT) comprises a wide variety of devices with different computing power, communication protocols, and energy needs. It is difficult to coordinate the energy-efficient functioning of heterogeneous devices in a network. In order to provide interoperability and standardized energy optimizations strategies, standardization activities are necessary.

3.3. Intermittent Connectivity

IoT devices frequently function in settings with sporadic or unstable connectivity. Energy-efficient techniques for data synchronization, reconnection, and communication protocols are crucial to minimizing energy usage during idle periods in settings where devices regularly lose and regain network access.

3.4. Data Processing and Transmission Overhead

The processing and transmission of data in IoT networks contribute significantly to energy consumption. Inefficient data handling, unnecessary transmissions, and high communication overhead can lead to increased power usage. Optimizing data processing at the device level and implementing energy-efficient communication protocols are critical for mitigating this challenge.

3.5. Security Mechanisms

Strong security features must be implemented in IoT devices in order to safeguard private information and guarantee network integrity. However, extra processing overhead from security measures like authentication and encryption might result in higher energy usage. It is a difficult task to strike a balance between energy efficiency and security needs.

3.6. Environmental Impact

The entire environmental effect of IoT devices is influenced by their creation, use, and disposal. The carbon footprint related to producing and using these gadgets rises with increased energy use. When tackling the environmental effects of energy consumption from IoT devices, sustainable methods and environmentally friendly materials are crucial factors to take into account.

3.7. Dynamic Workloads and Resource Allocation

IoT devices frequently encounter fluctuating workloads and resource requirements as a result of shifting user interactions or environmental variables. Optimizing energy usage requires not only dynamically modifying device

settings, including CPU frequency and sensor activity, but also skillfully regulating these fluctuations in resource needs.

3.8. Scalability Issues

IoT networks' scalability makes it harder to manage an ever-growing number of devices. The issues of energy consumption are increased by large-scale deployments, necessitating scalable solutions for effective data management, network optimization, and device coordination.

4. State-of-the-Art Approaches for Energy Efficiency in IoT Devices

Technological developments have sparked creative solutions to the problems with energy consumption that come with IoT devices. The most advanced tactics available today use a variety of methods, such as smart software algorithms and hardware optimizations, to achieve maximum energy efficiency. The cutting-edge of implementation and research is highlighted by the following major strategies:

4.1. Low-Power Hardware Design

Sub-threshold Operation: Ultra-low power consumption during idle or low-activity times is made possible by designing IoT devices to run at sub-threshold voltages. By doing this, leakage currents are reduced and battery life is greatly increased.

Energy-Harvesting Integrated Circuits (EHICs): By adding energy-harvesting features straight into the integrated circuits of the device, ambient energy sources, such solar or kinetic energy, may be extracted and used to either complement or replace conventional power sources.

4.2. Energy-Efficient Communication Protocols

Low-Power Wide-Area Network, or LPWAN: NB-IoT (Narrowband IoT) and LoRa (Long Range) are two examples of LPWAN technologies that are intended to provide long-range communication with low power consumption. Applications that need for prolonged battery life and modest data rates are a good fit for these protocols.

Wake-up Radio: By putting in place a low-power wake-up radio, IoT devices may minimize the amount of time they spend in active mode and cut down on energy usage by waiting for a wake-up signal.

4.3. Edge Computing and Fog Computing

Edge Intelligence: By processing data at the network's edge, closer to the source, less data must be sent to centralized servers. Edge computing reduces communication overhead to maximize energy consumption.

Fog Computing: Fog computing is an extension of the edge computing paradigm that disperses computational resources over a larger network to allow for localized processing and lower the energy costs related to sending massive amounts of data to distant cloud servers.

4.4. Machine Learning for Energy Prediction and Optimization

Predictive analytics: Machine learning algorithms use past data to identify patterns and trends in energy usage. This allows for proactive changes to resource allocation and device settings for maximum energy efficiency.

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Dynamic Resource Allocation: Intelligent algorithms optimize processing power and communication bandwidth to fit the present workload, hence minimizing needless energy usage. They do this by dynamically allocating resources depending on real-time needs.

4.5. Energy Harvesting Technologies

Photovoltaic Cells: By directly integrating solar panels into Internet of Things devices, it is possible to harvest ambient light energy and provide a consistent and sustainable power source for low-power applications.

Kinetic Energy Harvesting: In situations when conventional power sources are unfeasible or unavailable, kinetic energy harvesting technology can power IoT devices by harnessing energy from motion and vibrations.

4.6. Sleep Modes and Dynamic Voltage and Frequency Scaling (DVFS)

Sleep modes: These save energy without sacrificing responsiveness by putting Internet of Things devices into low-power states while they're not being used.

DVFS: By optimizing energy usage without compromising performance, devices with Dynamic Voltage and Frequency Scaling (DVFS) may dynamically modify their operating voltage and frequency based on the demands of the present processing.

The integration of these cutting-edge methodologies enhances the energy efficiency of Internet of Things devices and helps to meet the rising need for long-lasting and sustainable deployments across a range of sectors and applications. Aiming to further develop and create energy-efficient solutions for the changing Internet of Things, these fields are the focus of ongoing research.

5. Future Directions

Future directions in research and energy-efficient solutions as the Internet of Things (IoT) continue to emerge. The areas listed below indicate possible directions for research and creativity:

5.1. Integration of Renewable Energy Sources

Vision: Sustainable and continuous power generation may be facilitated by the direct integration of renewable energy sources, such as solar, wind, and kinetic energy harvesting, into IoT devices.

Techniques: Creating Internet of Things devices that integrate conventional energy sources with renewable alternatives to provide consistent and dependable power is known as hybrid power systems. Innovative techniques to effectively capture ambient energy and transform it into electrical power that may be used is known as advanced energy harvesting technologies.

5.2. Block chain for Energy-efficient Transactions

Vision: Ensuring safe and transparent energy consumption by utilizing block chain technology to improve energy efficiency in Internet of Things transactions.

Techniques: Using smart contracts to automate and save energy during transaction verification will cut down on computational overhead. Block chain-powered decentralized energy markets are being investigated in order to optimize energy allocation and use in Internet of Things networks.

5.3. Swarm Intelligence for Network Optimization

Vision: Reducing energy usage in IoT networks by optimizing communication and resource allocation through the application of swarm intelligence techniques.

Techniques: Distributed intelligence is the application of decentralized algorithms for data routing and communication that are modelled after the behavior of swarms. The design of Internet of Things networks with adaptive network topologies reduces energy-intensive data transmission by constantly adapting their structure to real-time requirements.

5.4. Advancements in Battery Technologies

Vision: Improving battery technology to get beyond present constraints and give Internet of Things devices more energy density, longer lifespans, and quicker charging times.

Techniques: Exploring the use of solid-state batteries, which offer higher energy density and enhanced safety, in Internet of Things devices. Examining self-charging techniques, such thermoelectric or piezoelectric harvesting, might help lessen the need for external power sources.

5.5. Human-Centric Design for Sustainable IoT

Vision: To promote energy-efficient usage, IoT devices should be designed with user needs, preferences, and sustainable practices in mind.

Techniques: User education involves educating people about the implications of IoT devices' energy consumption and promoting appropriate use. Creating user interfaces that dynamically modify a device's functionality in response to user behavior in order to improve both user experience and energy efficiency is known as adaptive user interfaces.

To propel research in these future areas, cooperation between the academic community, business community, and policymakers must continue. The Internet of Things ecosystem may develop towards more robust, sustainable, and energy-efficient solutions by investigating these creative approaches, guaranteeing a well-balanced integration of technology with social and environmental requirements.

6. Conclusions

In conclusion, for the broad and sustainable deployment of linked technologies, it is critical to solve the urgent issue of energy efficiency in IoT devices. This study examined current approaches to reduce energy usage and examined the difficulties brought about by heterogeneity in devices, power and resource limitations. Considerable progress has been achieved in maximizing the performance of Internet of Things devices through low-power hardware designs, effective communication protocols, and energy-conscious software optimizations. Furthermore, creative ways to augment conventional power sources are provided via energy collecting methods and dynamic power management approaches.

In the future, integrating cutting-edge technologies like sophisticated battery technology and CPUs with low power consumption shows potential for improving energy efficiency in Internet of Things ecosystems. Collaborating

across disciplines and pursuing standardization are essential to developing a unified strategy for energy efficiency. Successful case studies demonstrate that putting these tactics into practice can result in noticeable advancements. A dedication to continuous research and development, together with an emphasis on multidisciplinary solutions, will be crucial in forming a more sustainable and energy-efficient future for IoT devices in the rapidly changing IoT ecosystem. The Internet of Things community can maintain the growth and societal advantages of this revolutionary technology by balancing innovation with environmental responsibility by implementing these techniques and investigating new avenues.

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Consent for publication

Both the authors contributed to the manuscript and consented to the publication of this research work.

References

[1] Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. Computer Networks, 54(15): 2787–2805.

[2] Pathirana, P.N., et al. (2017). Energy-efficient Internet of Things (IoT) for Environmental Monitoring: A Review. Sustainable Cities and Society, 30: 94–115.

[3] Perera, C., Zaslavsky, A., Christen, P., & Georgakopoulos, D. (2017). Context-aware computing for the Internet of Things: A survey. IEEE Communications Surveys & Tutorials, 16(1): 414–454.

[4] Gubbi, J., et al. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems, 29(7): 1645–1660.

[5] Guo, B., et al. (2016). Energy-Efficient Sensor Data Collection in IoT-Aided Industrial Cyber-Physical Systems. IEEE Transactions on Industrial Informatics, 12(2): 821–829.

[6] Dunkels, A., et al. (2004). The Contiki operating system. In Proceedings of the First IEEE Workshop on Embedded Networked Sensors (EmNets '04), Pages 35–38.

[7] Shi, W., Cao, J., Zhang, Q., Li, Y., & Xu, L. (2011). Edge computing: Vision and challenges. IEEE Internet of Things Journal, 3(5): 637–646.

[8] Bormann, C., Ersue, M., & Keranen, A. (2015). Termination of CoAP/TCP Connections. RFC 7925.

[9] Bonomi, F., et al. (2012). Fog computing and its role in the internet of things. In Proceedings of the First Edition of the MCC Workshop on Mobile Cloud Computing (MCC '12), Pages 13–16.

[10] Zhang, Y., Zhang, H., Chen, Y., & Song, H. (2015). Fog computing: A green model for Internet of Things. IEEE Access, 3: 1711–1718.

[11] Shi, W., et al. (2016). Edge Computing: Vision and Challenges. IEEE Internet of Things J., 3(5): 637–646.

[12] Kang, J., et al. (2017). Machine learning algorithms for energy prediction in IoT platforms. Future Generation Computer Systems, 76: 253–263.

[13] Yousefpour, A., et al. (2019). Machine Learning in the Internet of Things: A Comprehensive Survey. IEEE Communications Surveys & Tutorials, 21(4): 3039–3072.

[14] Ma, H., Zhou, J., Zhao, D., Huang, R., & Tang, S. (2019). A survey of energy consumption models in the Internet of Things. IEEE Access, 7: 107442–107456.

[15] Li, Y., Zhao, D., Liu, J., Zhang, Q., & Zhou, J. (2020). Deep reinforcement learning for energy-efficient Internet of Things in smart cities. IEEE Transactions on Industrial Informatics, 16: 1–1.

[16] Huang, K., et al. (2018). A Comprehensive Review of Energy Harvesting Technologies for IoT Devices. IEEE Access, 6: 30651–30674.

[17] Li, K., et al. (2020). Green Internet of Things for Smart World. IEEE Access, 8: 59164–59181.

[18] Chandrakasan, A., et al. (2000). Low-power CMOS digital design. IEEE Journal of Solid-State Circuits, 35(4): 472–484.

[19] Roy, N., Dubey, A., & Panda, P. (2013). Solar energy harvesting by smart PV panel for the Internet of Things applications. In 2013 Annual IEEE India Conference (INDICON), Pages 1–6, IEEE.

[20] Sudevalayam, S., & Kulkarni, P. (2011). Energy harvesting sensor nodes: Survey and implications. IEEE Communications Surveys & Tutorials, 13(3): 443–461.

[21] Ransford, B., et al. (2011). Mementos: system support for long-running computation on RFID-scale devices. In Proceedings of the 9th ACM Conference on Embedded Networked Sensor Systems (SenSys '11), Pages 70-83.

[22] Sanjith, S.M., & Manju Bargavi, S.K. (2023). Improvements in IoT-Based Monitoring of Energy Use. International Journal of Engineering Research and Applications, 13(4): 08–17.

[23] Yassein, M.B., et al. (2019). A Survey of Internet of Things (IoT): Architecture, Enabling Technologies, Security and Privacy, and Applications. Journal of King Saud University – Computer and Information Sciences.

[24] Li, J., et al. (2021). Towards Sustainable Internet of Things: A Survey on Blockchain-Based Systems. IEEE Access, 9: 19148–19169.

[25] Roman, R., Zhou, J., & Lopez, J. (2013). On the features and challenges of security and privacy in distributed Internet of Things. Computer Networks, 57(10): 2266–2279.

[26] Ray, P. P. (2016). Internet of Things for Smart Cities: Technologies, Big Data and Security. Springer.

[27] Liu, J., Zhang, Z., & Yan, W. (2021). A survey on blockchain for Internet of Things: Architecture, consensus, privacy protection, and applications. IEEE Internet of Things Journal, 9(3): 2504–2530.